Chapter 2
Lung Volumes

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Abstract Measuring the subsegments of lung volume helps characterize certain disease states. These volumes are termed the static lung volumes, while spirometry measures the dynamic volumes. This chapter will discuss the static lung volumes, how they are measured and their clinical implications.

Keywords Total Lung Capacity (TLC) · Vital Capacity (VC) · Residual Volume (RV)

DEFINITIONS; SEE FIGURE 2.1

Total Lung Capacity (TLC)

- Is the volume of air (in liters) that a subject's lungs contain at the end of a maximal inspiration [1].

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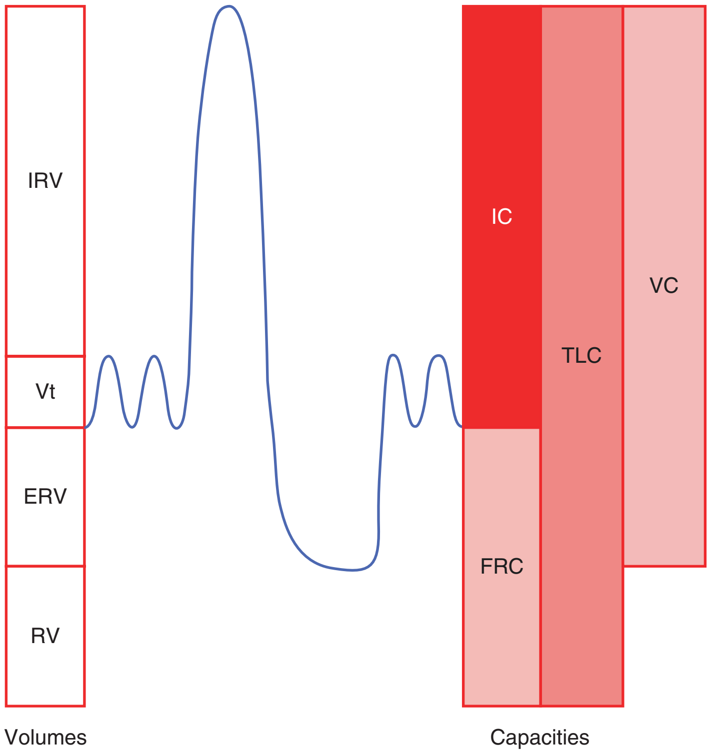

Figure 2.1 A volume spirogram showing the different lung volumes (*on the left*) and capacities (*on the right*)

Residual Volume (RV)

- Is the volume of air that remains in the lungs at the end of a maximal exhalation [1]. An abnormal increase in RV is called *air trapping*. The techniques used to measure lung volumes are primarily designed to measure the Residual Volume, as this volume can't be exhaled to be measured. The rest of the lung volumes can then be measured by simple spirometry, using the SVC maneuver rather than the FVC maneuver. The TLC can then be calculated by adding RV to VC or *functional residual capacity (FRC)* to *inspiratory capacity (IC)*; (Figure 2.1).

- So, spirometry is an essential part of any lung volume study.

Functional Residual Capacity (FRC)

- Is the volume of air that remains in the lungs at the end of a tidal exhalation, i.e. when the respiratory muscles are at rest [1]. This means that at FRC, the resting negative intra-thoracic pressure produced by the chest wall (rib cage and diaphragm) wanting to expand is balanced by the elastic recoil force of the lungs which naturally want to contract. Therefore, when the elastic recoil of the lungs decreases, as in emphysema, the FRC increases (hyperinflation), while when the elastic recoil increases as in pulmonary fibrosis, the FRC decreases.
- The FRC is the sum of the *expiratory reserve volume (ERV)* and the RV and is ~50% of TLC.
- FRC measured using body plethysmography (discussed below) is sometimes referred to as the *thoracic gas volume (TGV or V_{TG}) at FRC or V_{FRC}* [1]. Indeed, FRC is the volume measured by all the volume measuring techniques and RV is then determined by subtracting ERV.
- FRC has important functions:
  - It aids mixed venous blood oxygenation during expiration and before the next inspiration.
  - Decreases the energy required to re-inflate the lungs during inspiration. If for example each time the patient exhaled, the lungs fully collapsed, a large effort would be needed to re-inflate them. Such effort would soon result in exhaustion and respiratory failure [2].

Expiratory Reserve Volume (ERV)

- Is the maximum volume of air that can be exhaled at the end of a tidal exhalation and can be measured by simple spirometry [1].

Inspiratory Reserve Volume (IRV)

- Is similarly defined as the maximum volume of air that can be inhaled following a tidal inhalation [1].

Inspiratory Capacity (IC)

- Is the maximum volume of air that can be inhaled after a normal tidal exhalation [1]. Accordingly, IC equals the IRV + Tidal volume (V_T).

Tidal Volume (V_T)

- Is the volume of air that we normally inhale or exhale while at rest, and equals roughly 0.5 liter in an average adult and increases with exercise.

SVC or VC

- Was discussed in Chapter 1. See Figure 2.6.

The Terms: "Volume" and "Capacity"; (Figure 2.1) [3]

- The term "volume" refers to the lung volumes that can't be broken down into smaller components (RV, ERV, V_T and IRV).
- While, the term "capacity" refers to the lung volumes that can be broken down into other smaller components (IC, FVC, TLC and VC)
  - IC = IRV + V_T
  - FRC = ERV + RV
  - VC = IC + ERV
  - TLC = VC + RV

Correlation with the FV Curve

- FV curve can be used as a volume spirogram (seen in Figure 2.1), in addition to its other uses; (Figure 2.2). The only three lung volumes that spirometry can't measure are RV, FRC and TLC.

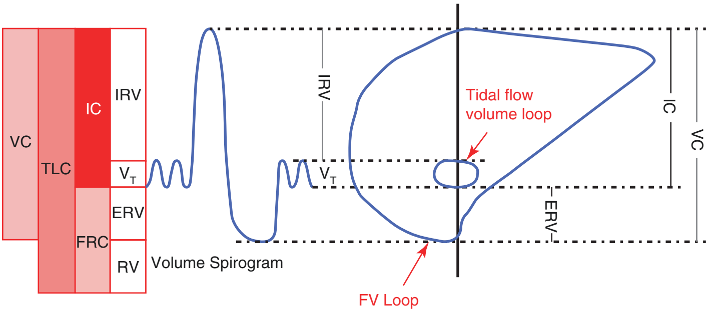

FIGURE 2.2 To aid in understanding lung volumes as they relate to the FV curve, the FV curve may be rotated 90° clockwise and placed beside the volume spirogram

METHODS FOR MEASURING THE STATIC LUNG VOLUMES

- There are different ways of measuring the lung volumes, the most accurate and widely used of which is the body box or body Plethysmography. The other, less widely used, methods are the nitrogen washout method, the inert gas dilution technique and the radiographic method.
- This section will discuss the principles, the advantages and the disadvantages of each method.

Body Plethysmography (Body Box)

- This is an ingenious way of measuring the lung volumes. The primary goal is to measure the FRC by the body box, in addition to allowing measures of the ERV and the SVC. The RV and TLC can then be calculated from these 3 variables, (RV = FRC – ERV; TLC = RV + SVC); see Figure 2.1.
- The principle of body plethysmography depends on *Boyle's law* which states that the product of pressure and volume of a gas is constant at a constant temperature [4, 5]. For the details of how this law is applied in the body box to get the FRC, see Table 2.1.

Table 2.1 Principle of Body Plethesmography

Figure 2.3

Body Plethysmography, Principle: [1, 4, 5]

The principle of body plethysmography depends on Boyle's law which states that the product of pressure and volume ($P \times V$) of a gas is constant under constant temperature conditions (which is the case in the lungs):

Therefore: $P_1 \times V_1 = P_2 \times V_2$

The patient is put in the plethysmograph (an airtight box with a known volume), with a clip placed on the nose, and the mouth tightly applied around a mouth-piece. The patient is then instructed to breathe at the resting tidal volume (V_T). The first part of the equation, above (Boyle's law) can then be applied at the patient's FRC (the end of a normal exhalation), where:

- P_1 is the pressure of the air in the lungs at FRC (the beginning of the test), which equals the barometric pressure (760 cmH_2O, at sea level)
- V_1 is the FRC (V_{FRC}) that is the volume of air in the lungs at the beginning of the test

At FRC, a valve (shutter) will close and the patient will perform a panting maneuver through an occluded airway where the change in pressure will be measured (ΔP)

The air in the lungs will get compressed and decompressed as a result of the change in pressure, resulting in a change in lung volume, i.e. a change in FRC (ΔV). We can now apply the new pressure and volume on the second part of the same equation, above, where:

- P_2 (the pressure of air in the lungs when the air gets decompressed as a result of the negative pressure produced by the inspiratory muscles during the panting maneuver, after the valve closure) will equal the initial pressure (P_1) minus the change in pressure (ΔP), i.e. $P_2 = (P_1 - \Delta P)$.
- Similarly, V_2 (the volume of air in the lungs after it gets decompressed) will equal the sum of the initial volume of the lung (V_1 or V_{FRC}) plus the change in volume (ΔV). So, $V_2 = (V_1 + \Delta V)$
- By substituting these values in the original equation ($P_1 \times V_1 = P_2 \times V_2$), we will get:
  - $P_1 \times V_1 = (P_1 - \Delta P) \times (V_1 + \Delta V)$; multiplying $(P_1 - \Delta P)$ by $(V_1 + \Delta V)$:
  - $P_1 \times V_1 = (P_1 \times V_1) + (P_1 \times \Delta V) - (\Delta P \times V_1) - (\Delta P \times \Delta V)$; subtracting $(P_1 \times V_1)$ from both sides:

TABLE 2.1 (continued)

- $0 = (P_1 \times \Delta V) - (\Delta P \times V_1) - (\Delta P \times \Delta V)$; adding $(\Delta P \times V_1)$ to both sides:
- $(\Delta P \times V_1) = (P_1 \times \Delta V) - (\Delta P \times \Delta V)$; dividing by ΔP
- $(\Delta P \times V_1)/\Delta P = [(P_1 \times \Delta V) - (\Delta P \times \Delta V)]/\Delta P$ **OR** $V_1 = [\Delta V \times (P_1 - \Delta P)]/\Delta P$
- As ΔP is too small compared to P_1 (20 cmH_2O compared a barometric pressure of 760 cmH_2O), then we can accept: $P_1 - \Delta P = P_1$. Then, the final equation can be simplified as follows: $V_1 = (\Delta V \times P_1)/\Delta P$ **OR** $V_{FRC} = (\Delta V \times P_1)/\Delta P$; as P_1 is the barometric pressure; each of ΔP and ΔV are measured by the plethysmograph
- After determining the FRC, the RV and TLC can be calculated, as discussed earlier. You don't need to worry about all of this, as a computer does all the measurements and calculations, but it is still good to know the calculation
- In plethysmography, the FRC is sometimes referred to as the thoracic gas volume (TGV or V_{TG})

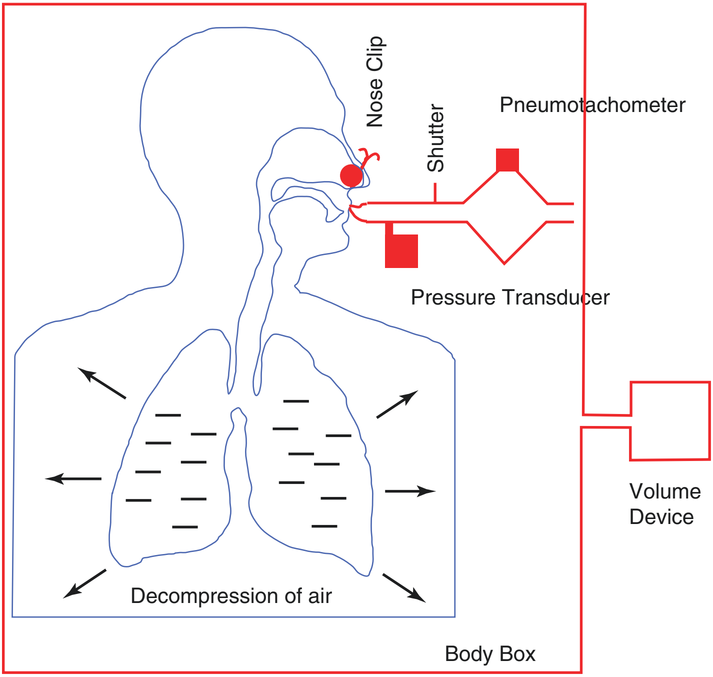

FIGURE 2.3 Principle of body plethesmography (the body box)

- The plethysmograph is the most popular way of measuring the lung volumes, as it is the fastest and probably the most accurate, but it is the most expensive, too. A comparison between the methods for measuring the lung volumes is shown in Table 2.4 [5, 6].

Nitrogen Washout Method [1, 7]

- This is another way of determining FRC. This technique is less accurate and more time consuming (at least 7 minutes [8]). Its principle is related to the concentration of nitrogen in the lungs (which is the concentration of the atmospheric nitrogen, 80%), which then can be washed out to determine the FRC volume. See Table 2.2 for details.

Table 2.2 Nitrogen washout method [1, 7]

Figure 2.4
At FRC (the end of a normal exhalation), the patient will breathe into a closed system. He/she will inhale 100% O_2 and exhale into a separate container with a known volume. The patient will continue this process, until almost all the nitrogen in the lungs is exhaled into that container. The nitrogen concentration in the container is then determined
The equation of the concentration (C) and volume (V) can then be applied: $C_1 \times V_1 = C_2 \times V_2$, where: ∘ C_1 is the N_2 concentration in the lungs at FRC (80%) ∘ V_1 is the FRC (unknown) ∘ C_2 is the N_2 concentration in the container (known) ∘ V_2 is the volume of air in the collecting container (known)
The FRC can then be determined. Keep in mind that two correction factors are used for accurate results. One is to account for the N_2 that remains in the lungs at the end of the test and the second is to account for the N_2 that is continuously released from the circulation into the lungs during the test
In obstructive disorders, more time (20 minutes) than usual is needed to washout N_2 from the poorly ventilated areas, resulting in under-estimation of the lung volumes. The test is normally terminated after 7 minutes [8], while body plethysmography is usually carried out over less than a minute. A significant increase in TLC measured by plethysmography compared to N_2 washout method suggests air trapping commonly seen in obstructive disorders (COPD)

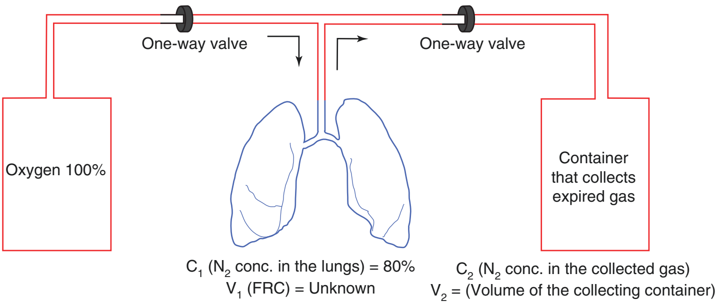

FIGURE 2.4 Principle of Nitrogen washout method

TABLE 2.3 Inert gas dilution technique [1, 9, 10]

Figure 2.5
At FRC (the end of a normal exhalation), the patient will breathe into a closed system with a known volume (V_1) and concentration (C_1) of an inert gas (Helium, He). The patient will continue breathing the Helium until concentration equilibrium is reached and measured by a Helium analyzer (C_2). V_2 will be the sum of the original volume of Helium (V_1) and the initial lung volume (FRC)
The equation of the concentration (C) and volume (V) can be applied to get the FRC as follows:
○ $C_1 \times V_1 = C_2 \times V_2$, where $V_2 = (V_1 + \text{FRC})$, therefore: $C_1 \times V_1 = C_2 \times (V_1 + \text{FRC})$
$\text{FRC} = [(C_1 \times V_1)/C_2] - (V_1)$ $= V_1 \times [(C_1/C_2) - 1] = V_1 \times [(C_1/C_2) - (C_2/C_2)]$ $= V_1 \times (C_1 - C_2)/C_2$

Inert Gas Dilution Technique [1, 9, 10]

- An inert gas is a gas that is not absorbable in the air-spaces. As in N_2 washout method, the inert gas technique is less accurate (under-estimates lung volumes in airway obstruction) and is more time consuming. See Table 2.3 for details.

Radiographic Method (Planimetry or Geometry)

- The TLC and RV are estimated by doing PA and lateral chest radiographs during full inspiration (TLC) and full expiration

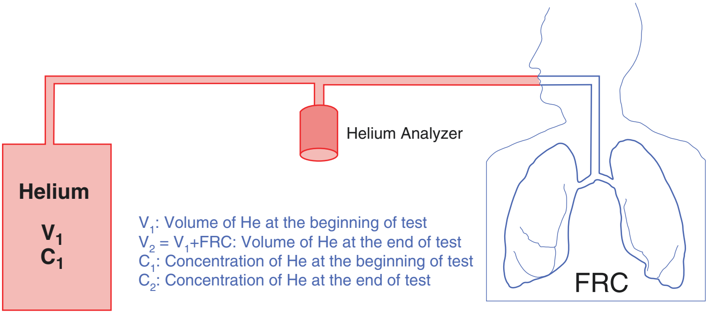

Figure 2.5 Principle of Inert Gas (Helium) Dilution Technique

Table 2.4 Comparison between the common methods for measuring lung volumes [5, 6]

Plethysmography	N_2 washout method/Inert gas dilution technique
Fast	Time consuming
Readily repeatable for reproducibility	Difficult to repeat [1, 10]. The test is too long [1]; (more time is required for the lungs to equilibrate and to clear inert gas in the dilution technique)
More accurate	Less accurate
Slightly over-estimates FRC in obstructive disorders [5]	Under-estimates FRC in obstructive disorders
Difficult to test patients on wheel chairs or stretchers or patients attached to i.v. pumps	Possible to test patients on wheel chairs or stretchers
Expensive, large size and complex	Cheaper equipment

(RV). It is a method that is not used routinely, due to the unnecessary exposure to radiation. This method may yield a lower TLC by >10% compared to plethysmography [11–13]. CT scan and MRI are more accurate than radiography in determining TLC but they are more costly [14–16].

- In a normal subject, all the above mentioned methods should give similar values for the lung volumes, if done properly [1]. It is only in disease states, that the values will vary to any significant degree between the different methods; Table 2.4.

TECHNIQUE FOR BODY PLETHYSMOGRAPHY

- The plethysmograph should be calibrated daily to ensure accuracy [1, 17–19]. The temperature and barometric pressure should be entered every morning.
- The patient sits comfortably inside the body box, with the door closed, a nose clip applied and the mouth tightly applied to a mouth-piece.
- The patient should breathe normally until 3 or 4 stable tidal breaths are achieved; (Figure 2.6). Then, (Step 1) at the end of the last tidal exhalation (FRC), the patient is instructed to pant fast and shallowly [20] against a closed valve (shutter), where the plethysmograph measures the FRC, as explained earlier.
- Step 2: the patient is then instructed to take a full inspiration (IC) then (step 3) deep, slow expiration (SVC or VC) for at least 6 seconds, which is spirometry but an unforced maneuver. The subsets of lung volume can then be calculated, as shown in Figure 2.6.[1]
- The test is then repeated for reproducibility as ATS criteria should also be met in the measurements. The difference between the two measurements of FRC and TLC should be within 10% and RV within 20% [1].
- Physical and biological calibrations are also needed.
  - The physical calibration is done every morning and includes calibrating the mouth pressure transducer and the volume signal of the plethysmograph. The volume calibration is carried out using a container with a known volume (a 3-liter syringe) where the container's gas volume measurements should be within 50 ml or 3% of each other, whichever is larger [1, 5].
  - Biological calibration should be done once a month on two reference subjects [1]. Measurements shouldn't be significantly different from the previously acquired measurements in the same subjects (<10% for TLC and FRC and <20% for RV) [1].

[1] In some labs, the patient is instructed to exhale fully after the panting maneuver to measure ERV then to inhale fully to measure VC.

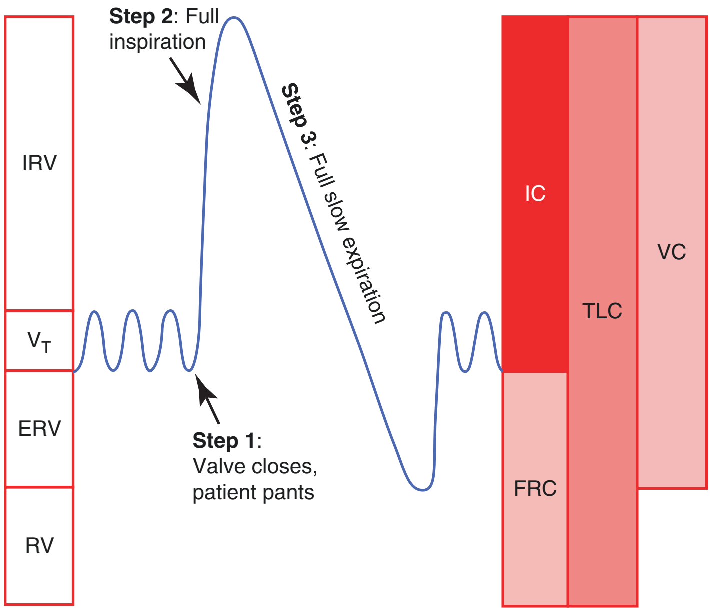

FIGURE 2.6 Technique for plethysmography. Notice that SVC is used instead of FVC

CORRELATING THE FLOW VOLUME CURVE WITH LUNG VOLUMES

- When the FV curve is done while the patient is inside the body box, at the same time as the lung volume study, the TLC and RV can be accurately plotted on the curve too. As discussed in Chapter 1, TLC is represented by the left-most point of the curve and RV by the right-most point of the curve. Comparing these points with their equivalents in the predicted curve, will indicate whether these lung volumes are decreased, normal or increased.
- In restrictive disorders, the TLC and RV are low, which means that the curve will shift to the right compared to predicted (remember, *r*ight = *r*estrictive). The opposite is true in obstructive disorders where lung recoil is reduced i.e. emphysema, see Figure 2.7.

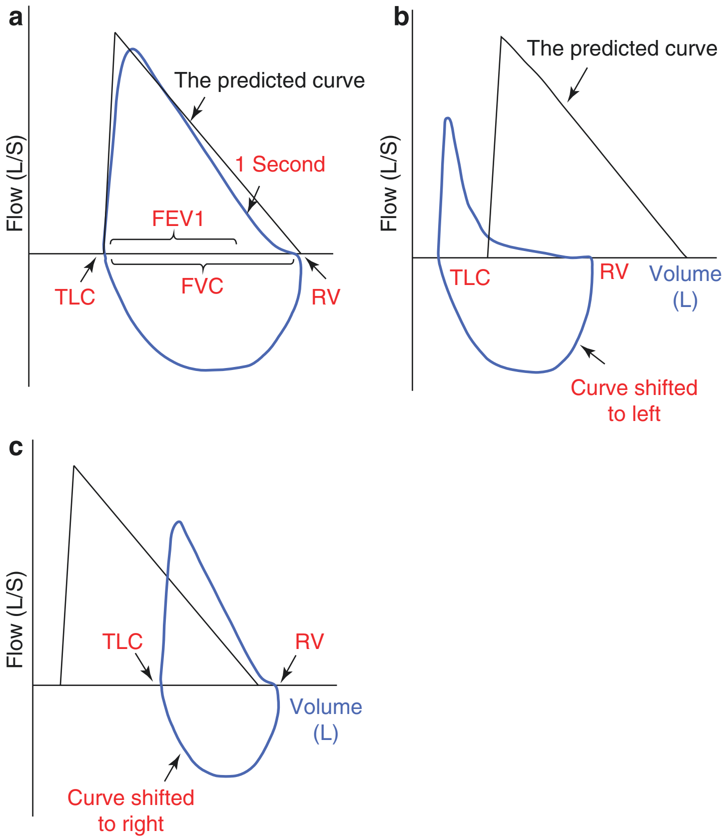

FIGURE 2.7 (**a**) Represents the ideal curve; (**b**) represents an obstructive disorder with increased TLC and RV and shift of FV curve to the left; (**c**) represents a restrictive disorder with decreased TLC and RV and shift of FV curve to the right

REFERENCE VALUES [1, 6, 18, 21–24]

- As with older spirometry databases, lung volume reference values were derived from Caucasian studies [25], and there remains a paucity of lung volume for other ethnic groups and therefore corrections need to be made for ethnic variability. These reference values are related to body size, with the height being the most important factor. Values above the fifth percentile are considered normal.

COMPONENTS OF A LUNG VOLUME STUDY

- The simple rule for lung volumes is that they increase in obstructive disorders and decrease in restrictive disorders. TLC and RV are the most important for interpreting PTFs. The RV/TLC ratio is similarly useful in interpreting lung volume studies. Table 2.5 discusses the causes for abnormal lung volumes. IC and IRV are not discussed as they have little diagnostic role.

CLINICAL SIGNIFICANCE OF FRC

- A high FRC (as in emphysema) means, the lungs contain more air than normal at rest. Breathing at that high lung volume helps prevent collapse of the airways and air trapping in emphysematous lungs, but at the same time, increases the effort of breathing. This can be very uncomfortable and lead to dyspnea. By way of example take a deep breath and try to talk and breathe at that lung volume and see for yourself. The increased effort noticed when breathing at high lung volumes is caused by two consequences of a high lung volume. Firstly, the breathing muscles are shortened and contract at a mechanical disadvantage. As a result, more muscular activity is required to produce the pressure gradient that leads to airflow and tidal volume. Secondly, the lungs are less compliant as lung volume increases above FRC (more elastic recoil) and so more force is required to produce airflow.
- When patients with emphysema exercise, their respiratory rate increases and the expiratory time decreases. The reduced expiratory time impairs lung emptying and leads to air trapping. The air trapping results in a progressive increase in the FRC with each respiratory cycle. This new volume is called End-Expiratory Lung Volume. This process continues until this volume approaches a critical point, at which time, the patient can't continue exercising. This phenomenon is called "*dynamic hyperinflation*" and is

Table 2.5 Causes of abnormal lung volumes

TLC

Increased in:

- COPD, mainly emphysema
- Acromegaly patients may have a high TLC [2], which can be differentiated from emphysema by RV/TLC ratio (normal in acromegaly and high in emphysema [26])
- TLC may be high in normal subjects with big lungs e.g. swimmers
- TLC is usually normal in asthma, as lung elastic recoil is normal [27]

Decreased in restrictive disorders [28] (see Table 1.7 for classification)

RV

Increased (air trapping) in obstructive disorders:

- COPD
- Asthma, although the TLC is normal, but the RV is high because of air trapping

Decreased in parenchymal restriction

RV/TLC ratio

Normal in parenchymal restriction [2]

Increased

- Mainly in obstructive disorders (very high in emphysema) [27, 28]
- Can be increased in chest wall restriction (because of normal RV and low TLC)

ERV

Decreased in

- Restrictive disorders, similar to TLC
- Obstructive disorders (because of the increased RV due to air trapping that occurs in these conditions)
- An isolated reduction in ERV is characteristic for obesity

FRC

Increased (hyperinflation) in

- Obstructive disorders, mainly emphysema due to loss of lung elastic recoil
- FRC increases slightly with aging

Decreased in

- Restrictive disorders, mainly lung fibrosis
- Obesity
- Supine position (abdominal organs push the diaphragm against the lungs)

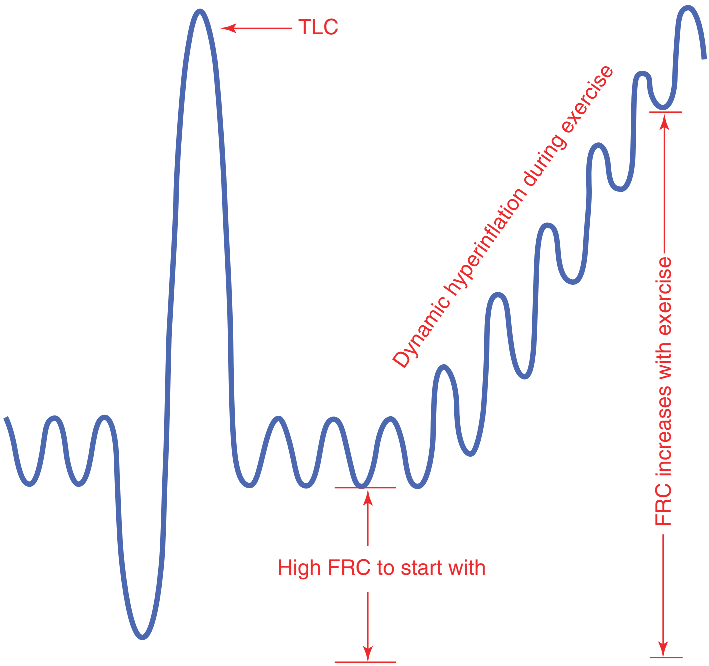

FIGURE 2.8 Dynamic hyperinflation in patients with emphysema during exercise. Note that V_T increases with exercise. Note also that the expiratory phase decreases progressively with continued exercise indicating progressive air trapping

characteristic of patients with emphysema and is responsible for much of their exercise limitation; Figure 2.8.

- Breathing at a low FRC, as in pulmonary fibrosis and obesity, can also increase the work of breathing. In restrictive lung disorders, the lung compliance is reduced which means more effort is needed to inflate the lungs.

DISEASE PATTERNS

The lung volumes are diagnostically useful in many ways. Table 2.6 summarizes their usefulness, which is discussed in more detail in this section:

Table 2.6 Additional information acquired by a lung volume study compared to spirometry

Differentiates the subtypes of obstructive disorders
Confirms the diagnosis of a restrictive disorder and separates its subtypes
Separates restrictive from obstructive disorders
Helps in detecting combined, obstructive and restrictive disorders

Defining Air Trapping and Hyperinflation in Obstructive Disorders

- Current guidelines do not specify a fixed cut off for TLC when defining hyperinflation however, a value greater than 120% predicted is generally considered to be indicative of hyperinflation
- Similarly, air trapping is identified by taking the upper limit of normal for RV in combination with an elevated percent predicted RV/TLC ratio. For example, if the measured RV is above the upper limit of normal and the ratio of RV over TLC is greater than 1.2 or 120%, then we have identified air trapping.
- *Differentiate subtypes of obstructive disorders*
  - Generally, obstructive disorders (emphysema and asthma) result in increased RV (air trapping) due to airway narrowing while TLC is increased only in emphysema due to loss of elastic recoil. In asthma, however, the lung has normal elastic recoil and, therefore a normal TLC [21].
  - The RV/TLC ratio may be increased in both emphysema and asthma. The RV/TLC ratio can be used also to differentiate an obstructive from a non-obstructive increase in TLC, like acromegaly (where the RV is increased but the RV/TLC ratio is normal) [2].
  - If lung volumes are measured pre- and post- bronchodilator, much can be learned from looking at the behavior of TLC and RV before and after the bronchodilator. TLC and RV may be shown to decrease following bronchodilator, even in the absence of a significant response in FEV_1 and FVC. Furthermore, IC may increase as FRC may decrease more than TLC in response to bronchodilators. In this case, an increase in IC gives patients with emphysema more room or time to breathe before they

develop dynamic hyperinflation to the point of stopping exercise. These volume changes indicate that the bronchodilators are clinically useful to such patients even though there is no change in FEV_1; (Figure 2.9) [17, 21, 29].

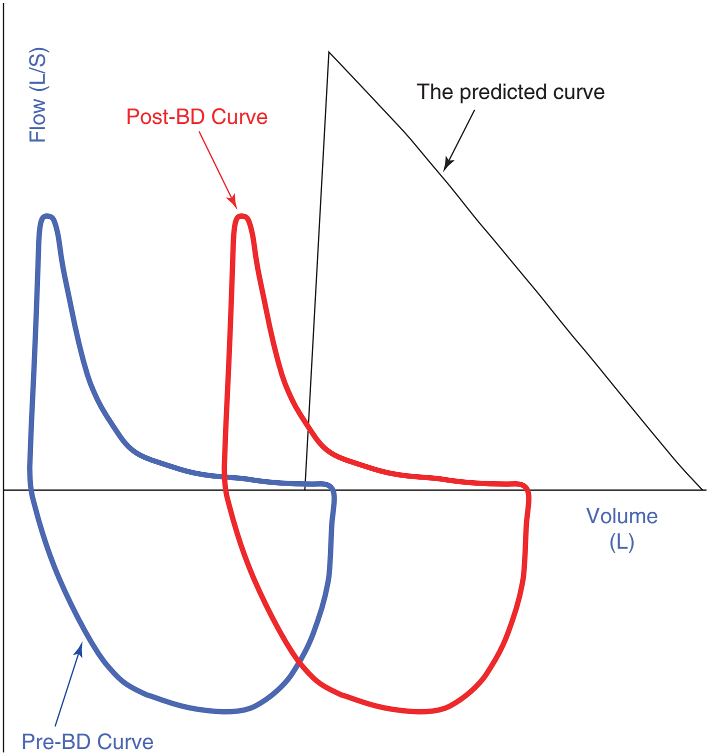

FIGURE 2.9 Post-BD curve is closer to predicted curve indicating significant reduction in TLC and RV compared to that in the pre-BD curve. The morphology of the curve has not changed indicating no improvement in FEV_1 or FVC. Despite that BD can be of help to such patients because of the lung volume change. Note that the change in TLC in this diagram is exaggerated

- *Confirm the diagnosis of a restrictive disorder and differentiate its subtypes*
  - A decreased TLC is essential to make the diagnosis of a restrictive disorder with confidence [21]. The RV and RV/TLC ratio, however, may be used to differentiate the subtypes of restriction:
    - (a) In a parenchymal restriction (lung fibrosis), where there is increased elastic recoil and loss of air space, the RV and TLC are reduced with a normal RV/TLC ratio (both RV and TLC decrease proportionately) [2].
    - (b) In chest wall restriction (NMD, musculoskeletal disease, paralyzed diaphragms and obesity), where the lung parenchyma is normal, the RV is usually normal (or increased) with an increased RV/TLC ratio (remember that TLC is low). In NMD, RV may be increased because the ERV can be very low due to weakness of the expiratory muscles.
    - (c) The diffusing capacity for Carbon monoxide (DL_{CO}) is a more reliable way of differentiation between parenchymal and chest wall restriction, as will be discussed in next chapter. *Maximal Voluntary Ventilation (MVV)* and *maximal respiratory pressures* are measures to help differentiate the different types of chest wall restriction.
      - Obesity and mild asthma can show a spirometric pattern consistent with mild restriction (decreased FVC and normal FEV_1/FVC ratio), the so called pseudorestriction. The way to differentiate parenchymal restriction from this pseudorestriction (caused by obesity or mild asthma) is by the IC/ERV ratio. This ratio is normally 2–3:1. This ratio decreases in parenchymal restriction to <2:1 and increases in pseudorestriction to >6:1. The maximal FV curve, combined with a FV curve during quiet breathing, can be used to make that distinction as in the Figure 2.10 [31].
      - Poor patient effort during spirometry may mimic a restrictive disorder, with low FVC and FEV_1 and a normal FEV_1/FVC ratio. In this case a normal TLC

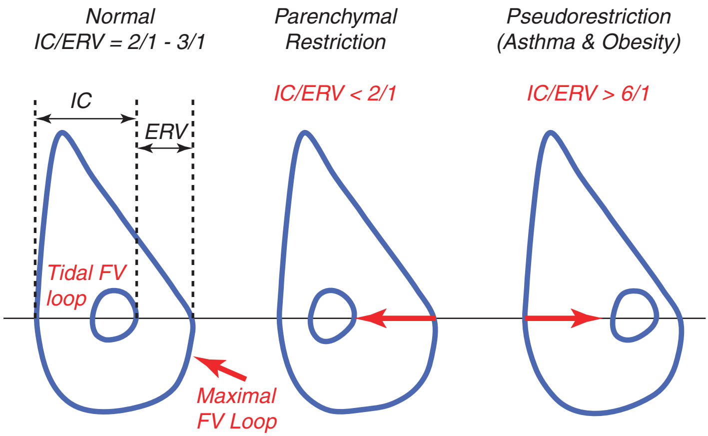

FIGURE 2.10 IC/ERV ratio is used to differentiate parenchymal restriction from pseudorestriction [30]

can exclude restrictive disorders, as body plethysmography doesn't need much patient effort to perform. The shape of the FV curve, can also easily exclude a poor effort study (PEF is not sharp and rounded in a poor effort study). In addition, the study is unlikely to be reproducible with a poor effort. The technicians usually indicate in their comments if a poor effort is apparent.

- *Separating obstructive from restrictive disorders*
  - Obstructive and restrictive disorders are sometimes hard to separate based on spirometry alone. Lung volumes may provide additional clues as they are generally increased with obstructive and decreased with restrictive disorders.
  - As an example, when the FEV_1 and FVC are at the lower limit of the normal range, with a normal FEV_1/FVC ratio, a lung volume study may be of value:
    (a) If the TLC and RV are high, then an obstructive disorder is most likely (RV/TLC ratio is usually high).
    (b) If the TLC is normal and RV is mildly increased, then mild asthma and air trapping could be responsible (RV/TLC ratio is high) [2]. In this case, the airway obstruction is not severe enough to cause a significant drop in

FEV$_1$ or their ratio. A bronchodilator study may show a significant response.

(c) If the TLC is low, then a restrictive defect is likely to be the cause, provided that FVC is below the fifth percentile (a normal FVC rules out restriction [32, 33]). Before you make such a conclusion, have a quick look at the FV curve and the rest of the PFT values. If all the values are decreased proportionately with a normal FV curve make sure a correction for ethnic background is not required.

(d) If the TLC and RV are normal, then the study is most likely normal.

- *Detection of combined disorders*
  - Combined disorders are hard to diagnose based on spirometry alone. Spirometry coupled with a lung volume study is very useful:
    (a) An obstructive disorder should be clear in spirometry, with low FEV$_1$/FVC ratio. If this airflow obstruction is seen with a reduced TLC, then the reduced TLC suggests an additional restrictive disorder [21, 28]. The RV could be low, normal or high as airway obstruction may result in air trapping and increased RV [1]. Combined defects can be seen in conditions like sarcoidosis or co-existing COPD and lung fibrosis.
  - Keep in mind that an obstructive disorder (like emphysema) with pulmonary resection (lobectomy or pneumonectomy) can give a similar pattern.
- Chapter 6 discusses the approach to such PFTs in detail.

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